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Post Detection Microdiversity and Dual Macrodiversity in Shadowed Fading Channels

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Introduction

In wireless communications the received signal can be affected by both short-term fading and long-term fading (shadowing). The short-term fading is a phenomenon which is the result of multipath propagation, while the shadowing is the result of the existence of large obstacles between transmitter and receiver. Above mentioned impairments in transmission can be mitigated using diversity techniques at single base station (microdiversity) and signal processing from multiple base stations (macrodiversity), simultaneously. In [1], the average power, which is random variable due to shadowing, is modeled using gamma distribution. A fading envelope is described by Rayleigh distribution. The Rayleigh distribution can be used to model only multipath fading with no direct line-of-sight (LOS) path. In most of published papers, it is used to describe interference signal envelope [2]. The Nakagami-*m* distribution has gained widespread application in modeling of physical fading radio channels. The primary justification of the use of Nakagami-*m* fading model is its good fit to empirical fading data. It is versatile and through its parameter *m*, we can model signal fading conditions that range from severe to moderate, to light fading or no fading. It includes the one-sided Gaussian distribution (m=0.5) and the Rayleigh distribution (m=1) as special cases. A composite analytical model assuming Nakagami-*m* density function for the envelope of the received signal and gamma density function for modeling the average power to account for shadowing can describe the shadowed fading channels [3-6].

In [6], the expression for the error probability following micro- and macrodiversity processing with maximal ratio combining (MRC) at the micro level and selection combining (SC) at the macro level is determined. A BPSK transmission is considered. The model assumed a Nakagami-*m* density function for the envelope of the received signal while using a correlated gamma density function to model the average power to account for the shadowing.

In paper [7], an application of the microdiversity with L correlated branches in Nakagami-*m* fading is considered. A post-detection product detector combiner (PDC) was applied as much easier for the implementation than a pre-detection MRC, while the performances of the receiver are not significantly impaired this way (showing limited losses in performances).

In this paper, we determine a closed form expression for the error probability following micro- and macrodiversity processing with an L branch PDC at the micro level and SC with two branches (dual diversity) at the macro level. We consider the 2-DPSK (differential phase-shift keying) signaling scheme. The model assumes Nakagami-*m* density function for the envelope of the received signal while using a gamma density function to model the average power to account for the shadowing. The effect of the correlation between the signals at two base stations is also investigated, while the channels of a single base station are assumed uncorrelated (separation between antennas is on the order of one half of a wavelength).

System model

In Fig. 1, the system model used in this paper is presented. The signal at the k-th receiver antenna of the i-th base station can be written as

$$r_{ik}(t) = R_{ik} e^{j\phi_{ik}} s_l(t) + n_{ik}(t), \quad k = 1,\dots,L, \quad l = 1,2, \quad i = 1,2, \tag{1}$$

where $s_l(t)$ represents the transmitted signal. At the q-th bit interval it can take value $s_1(t) = g(t - qT)e^{j\phi_0}$ or $s_2(t) = g(t - qT)e^{j(\phi_0 + \pi)}$ where $g(t)$ is an unit energy pulse and T is a bit interval. $n_{ik}(t)$ denotes an additive white Gaussian noise (AWGN) in the k-th branch of the i-th base station, which is assumed statistically independent in each branch, with one sided power spectral density N_0. The fading phase shift is denoted as ϕ_{ik} and R_{ik} is the fading amplitude which follows Nakagami-m probability density function (pdf) [7].

After matched filtering the signal on each branch, the post detection takes the unweighted sum of the outputs of the L differential products. Its decision variable in each base station, which is tested for being positive or negative, can be expressed as

$$Z_i = \mathrm{Re}\left[\sum_{k=1}^{L}\left(R_{ik}e^{j\phi_{ik}} + N_{ik2}\right)\left(R_{ik}e^{-j\phi_{ik}} + N_{ik1}^{*}\right)\right], i=1,2. \quad (2)$$

The AWGN components at the output of the matched filters in two consecutive bit intervals are presented as N_{ik_1} and N_{ik_2}.

The instantaneous signal-to-noise ratio (SNR) per bit in each base station γ_i, at the output of the post-detection PDC, can be written as

$$\gamma_i = \sum_{k=1}^{L}\gamma_{ik}, \quad (3)$$

where γ_{ik} is the instantaneous SNR at the input of the detector in the k-th branch at the i-th base station and can be also presented as $\gamma_{ik} = R_{ik}^2 T/(2N_0)$. The pdf of γ_{ik} follows the Gamma distribution

$$p_{\gamma_{ik}}(\gamma_{ik}) = \frac{(m/y_{ik})^m}{\Gamma(m)}\gamma_{ik}^{m-1}\exp\left(-\frac{m\gamma_{ik}}{y_{ik}}\right), \; \gamma_{ik} \geq 0 \quad (4)$$

In Eq. (4), $\Gamma(\cdot)$ is the Gamma function [8]. The input average SNR for the k-th branch at the i-th base station is denoted as y_{ik} and can be expressed by $y_{ik} = \Omega_{ik}T/(2N_0)$, where $\Omega_{ik} = \langle R_{ik}^2 \rangle$ is the mean square value of R_{ik} and $m \geq 0.5$ is the fading severity.

The average powers at two base stations are related to the random parameters y_i (i=1,2), signifying the existence of the shadowing. In practice, shadowing has a larger correlation distance and it is difficult to ensure that base stations operate independently, especially in microcellular systems. This means that y_1 and y_2 are correlated. As selection combining is applied at the macro level, the output of this processing is

$$Z_0 = \begin{cases} Z_1, y_1 > y_2, \\ Z_2, y_1 \leq y_2. \end{cases} \quad (5)$$

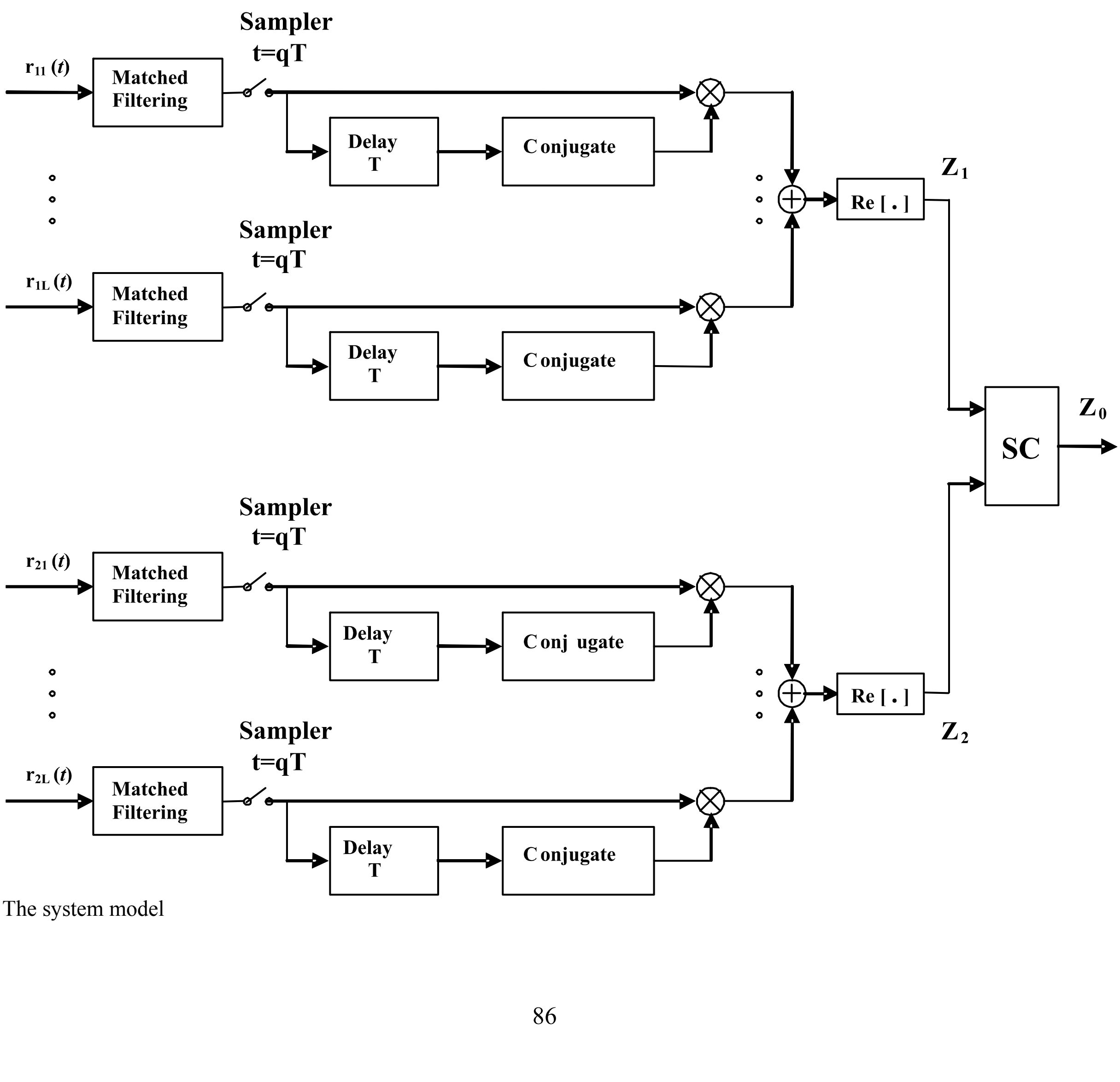

Fig. 1. The system model

Evaluation of the error probability

We can describe the performed derivation starting from the implementation of the diversity at the single base station (microdiversity). We treat L branches to be identical and independent. The conditional error probability of the SNR following the post-detection PDC [7] can be presented as

$$Pe_{|y_i} = \left(1+\frac{y_i}{m}\right)^{-Lm} \sum_{l=0}^{L-1} c_l \sum_{r=0}^{l} H_m(l-r) \sum_{p=0}^{r} H_m(r-p) \ldots$$

$$\cdots \sum_{q=0}^{\omega} H_m(\omega-q) H_m(q) \left(\frac{y_i/m}{1+y_i/m}\right)^{l}, \tag{6}$$

where it is:

$$c_l = \frac{1}{2^{2L-1}} \sum_{n=0}^{L-1-l} \frac{(2L-1)!}{n!(2L-1-n)!}, \tag{7}$$

$$H_m(h) = \Gamma(m+h)/(\Gamma(m)\Gamma(h+1)). \tag{8}$$

In this work, a dual diversity scheme will be considered for the implementation of the macrodiversity. If y_1 and y_2 are identically gamma distributed, the joint pdf of y_1 and y_2 can be expressed as

$$f(y_1, y_2) = \frac{\rho^{-\frac{1}{2}(c-1)}}{\Gamma(c)(1-\rho)\, y_0^{c+1}} (y_1 y_2)^{(c-1)/2} \times$$

$$\times \exp\left(-\frac{y_1+y_2}{y_0(1-\rho)}\right) \mathrm{I}_{c-1}\left(\frac{\sqrt{4\rho \cdot y_1 y_2}}{y_0(1-\rho)}\right), \tag{9}$$

where ρ is the correlation between y_1 and y_2, c is the order of gamma distribution, y_0 is related to the average power of y_1 and y_2 and $\mathrm{I}_{c-1}(\cdot)$ is the modified Bessel function of the first kind of the order (c-1) [8]. After the diversity combining at the micro and macro level, the error probability can be obtained from (6) and (9) as

$$P_e = \int_0^{+\infty} dy_1 \int_0^{y_1} dy_2 Pe_{|y_1} f(y_1, y_2) +$$

$$+ \int_0^{+\infty} dy_2 \int_0^{y_2} dy_1 Pe_{|y_2} f(y_1, y_2). \tag{10}$$

It is now possible to simplify Eq.(10) using a series expansion of the modified Bessel function [8] as

$$\mathrm{I}_\nu(u) = \sum_{k=0}^{+\infty} \frac{1}{\Gamma(k+1)\Gamma(\nu+k+1)} \left(\frac{u}{2}\right)^{2k+\nu}. \tag{11}$$

After putting the obtained expression in convenient form and using identities [8]:

$$\int_0^{u} x^{p-1} e^{-x} dx = e^{-u} \sum_{k=0}^{+\infty} \frac{u^{p+k}}{p(p+1)\cdots(p+k)}, \tag{12}$$

$$\int_0^{+\infty} e^{-px} x^{g-1} (1+ax)^{-\nu} dx =$$

$$= a^{-g}\Gamma(g)\Psi(g, g+1-\nu; p/a),$$

$$when\ \mathrm{Re}\{g\}>0, \mathrm{Re}\{p\}>0, \mathrm{Re}\{a\}>0, \nu \in \mathrm{C} \tag{13}$$

one can obtain the closed form expression for the error probability

$$P_e = \frac{2}{\Gamma(c)(1-\rho)\, y_0^{c+1}} \times$$

$$\times \sum_{k=0}^{+\infty} \frac{1}{\Gamma(k+1)\Gamma(c+k)} \frac{\rho^k}{\left(y_0(1-\rho)\right)^{c+2k-1}} \times$$

$$\times \sum_{j=0}^{+\infty} \frac{\left(y_0(1-\rho)\right)^{-j}}{\prod_{s=0}^{j}(c+s+k)} \sum_{l=0}^{L-1} c_l \times$$

$$\times \underbrace{\sum_{r=0}^{l} H_m(l-r) \sum_{p=0}^{r} H_m(r-p) \cdots \sum_{q=0}^{\omega}}_{L-1} H_m(\omega-q) \times$$

$$\times H_m(q)\, m^{2c+2k+j}\, \Gamma(2c+ek+j+l) \times$$

$$\times \Psi\left(2c+2k+j+l, 2c+2k+j+1-Lm; \frac{2m}{y_0(1-\rho)}\right), \tag{14}$$

where $\Psi(\cdot\ ,\ \cdot\ ;\ \cdot)$ represents the confluent hypergeometric function [8].

In Fig. 2, the dependence of the error probability on the average SNR for the suggested diversity system, obtained from Eq. (14), is presented.

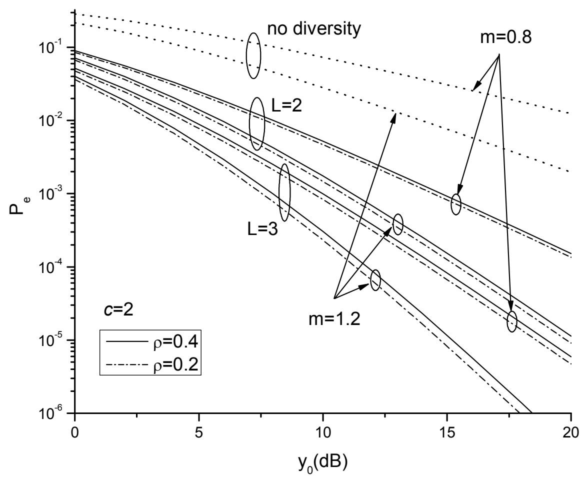

Fig. 2. Error probability as a function of y_0

The parameters are the number of microdiversity branches L, the correlation coefficient of the macrodiversity branches ρ and the fading severity m. As it is known, the increase of the number of branches causes the error probability to decline, while the increase of the correlation coefficient impairs the performances of the system. Also, system performance improves as severity of fading decreases (i.e. m increases). Fig. 2 confirms that the simultaneous use of both micro- and macrodiversity is reasonable.

Conclusions

In this paper we determine a closed form expression for the error probability of the system including micro- and macrodiversity processing. Although the pre-detection MRC is considered to be the optimal combiner, its realization is very complex. Thus, the use of the post-detection PDC at the micro level diversity is chosen in this paper. This diversity scheme is simple for realization and it shows limited losses comparing to the ideal pre-detection MRC, as it is shown in [7]. At the macro level, SC with two branches is considered and the influence of the correlation between the signals in those branches is taken into account.

The obtained closed form expression for the error probability can be employed in the parameter optimization of diversity systems in different propagation conditions.

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In this paper we determine a closed form expression for the error probability following micro and macro diversity processing with an *L* branch post-detection product detector combiner (PDC) at the micro level and a selection combining (SC) with two branches (dual diversity) at the macro level. We consider the 2-DPSK signaling scheme. The model assumes a Nakagami density function for the envelope of the received signal while using a gamma density function to model the average power to account for the shadowing. The effect of the correlation between the signals at the output of two base stations is also investigated. Ill. 2, bibl. 8 (in English; abstracts in English and Lithuanian).

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Analizuojama klaidos tikimybės uždaros formos išraiška, skirta pavėluotiems mikro- ir makroįvykiams nustatyti. Pasiūlyta 2-PDSK signalizavimo schema. Toks modelis paremtas Nakagami tankio funkcija. Tirta dviejų bazinių stočių išėjimo signalų koreliacija. Il. 2, bibl. 8 (anglų kalba; santraukos anglų ir lietuvių k.).